Critique of Incident

"Improper Modification of High Voltage Connections to Kepco Power Supply"

July 15, 2004

Prepared by

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I. **Purpose** - This critique was conducted to establish the sequence of events and determine the causal factors that resulted in the improper modification of the high voltage connections to a Kepco Power Supply at beam line U4A. An initial meeting was held 6/4/04 to gather information and to evaluate circumstances surrounding the event. This meeting was attended by: J. Aloi (NSLS), A. Boerner (NSLS), R. Casey (NSLS), S.Y. Ally Chan (Rutgers) B. Clay (NSLS), S. Hulbert (NSLS), A. Kuczewski (NSLS), L. Plucinski (Boston University), H. Wang (Rutgers). Additional information regarding the sequence of events was obtained from R. Opila, A. Mathew, and K. Demirkan from the University of Delaware via telephone discussion and emails.

II. **Introduction** – The U4A beam line is designed for UV photoelectron spectroscopy and is managed by a consortium of institutions involving the NSLS, the Army Research Office, Rutgers, and Boston University. Co-spokespersons for the beam line are from the NSLS and the Army Research Office. Co-local contacts for the beam line are from Rutgers and the NSLS.

This beam line is primarily used for surface and near-surface studies of metallic and semiconducting materials. As a part of the beam line set-up for experiments, a 2000 V 100 mA DC power supply (Kepco BHV-2000) is provided and has been configured to establish a positive bias on the sample to permit electron heating.

In this incident, the high voltage connections to the power supply were modified in an effort to establish a 100-volt negative bias on the sample. The modification to the connections was improperly done, resulting in the inoperability of the power supply and creating an electrical shock hazard on the shields of the SHV connectors of the high voltage cable.

III. **Sequence of Events**

Week of May 17th – Rutgers PRT members use beam line with power supply configured to provide + 1.2 KV bias to sample. Everything is normal.

May 20 - 29 - A general user team consisting of two graduate students from the University of Delaware began operation at the beam line on May 20th and continued until May 29th. During the run they developed a need to provide a negative bias to their sample in order to improve the detection efficiency of the low energy photoelectrons emitted from their sample. Initially, following guidance received from the Rutgers co-local contact, they provided a negative 9-volt bias using a small DC power supply. Later, they wanted to bias the sample at negative 100 V to reproduce a similar experiment that they had performed at the Stanford Synchrotron Laboratory. On or about May 25 they discussed the possibility of providing a negative bias using

the high voltage power supply with the NSLS beam line co-spokesperson, but did not discuss any details about how the change would be done. Later, without discussion or review with others, the students removed the protective cage at the rear of the power supply and reversed the existing connections for the center conductor and the grounded copper sheathing (see attachment 1). They reported that they observed no output or other indication that the power supply was working in this configuration; the students abandoned their effort to provide a negative bias using the high voltage power supply. The students did not restore the previous configuration and did not advise anyone of the changes that they had made.

May 29 – June 1 - A Boston University post-doc began a scheduled run on May 29th at U4A. In his experiment he needed to provide electron beam heating to clean his sample periodically, but when he sought to use the high voltage power supply he found that the 120 VAC power cord was not fully seated at the rear of the unit. After reconnecting the power cord, he then found that the power supply would operate only in a "current limit mode", indicating that the power supply output was shorted to ground at some location in the circuit. He tried intermittently over the next several days to identify the problem, but was unsuccessful due to his lack of familiarity with the equipment. He did discuss the prblem twice with the Rutgers local contact.

June 2nd – The co-local contact from Rutgers and a colleague arrived at the beam on June 2 and began to evaluate the power supply which was needed for their experiment. They typically performed electron beam heating of their sample with the power supply set at 1.2 to 1.4 kV. They confirmed the problem identified by the previous user and quickly determined that there was no short within their sample or vacuum tank. They subsequently found that the SHV connector shield of the high voltage cable was electrically energized when the power supply was on and immediately took the power supply out of service. They reported the problem to NSLS beam line personnel who took possession of the power supply. During their testing of the equipment, they limited the power supply output to ~200 V and handled the cables and connectors after turning off the power supply.

IV. Discussion

- U4A is a productive beam line that lacks PRT management with sufficient resources to provide support and oversight of the beam line on a full-time basis. In an effort to maintain the viability of the beam line, the NSLS has provided additional support to augment the limited staffing of the PRT – hence the involvement of NSLS personnel as the co-spokesperson and the co-local contact. However, this type of support is of a limited nature and does not provide on-going involvement during the operation of the beam line.

- The two students that made the modifications to the high voltage connections were on their 4th visit to the NSLS since January 2004. They had been supervised during the first two visits by more experienced personnel; this was their second independent visit to operate the beam line. All required NSLS training for work at

the beam line was current. They were judged by their colleagues to be knowledgeable and capable to handle the operational activities at the beam line. One of the two users had been identified as the lead experimenter when the beam line was enabled and was responsible for the conduct of the experiment during the run.

- Configuration control of a beam line and associated equipment is important to ensure that safe conditions are maintained during operations. It is strongly emphasized in the roles and responsibilities issued last year for the beam line staff and user groups. It is specifically the responsibility of the lead experimenter and the local contact to ensure that important configuration changes are reviewed for safety prior to any change.

- The two students had discussed the need for negative biasing with the co-local contact from Rutgers and the co-spokesperson from the NSLS prior to the modification of the high voltage connections. The discussions had been limited and focused on general concepts rather than specific details. There was no discussion or review of the actual changes that were made either before or after the changes. The NSLS staff member serving as the co-local contact for the beam line reported that he made daily stops at the beam line to see how things were going during this run, but that there had been no discussion of the sample biasing issue and the need to modify the power supply connections.

- The Kepco BHV – 2000 DC power supply involved in this incident is an older model and has no documentation accessible at the beam line. There is no SHV output port to permit direct hook-up by a SHV connector and there is no direct means available to reverse polarity. In order to access the high voltage connections on the power supply, the students had to remove the enclosures at the rear of the power supply. There was no documentation available to assist them in identifying how to establish the polarity change in a safe manner.

- The power supply has two additional issues of concern observed by the review team. There are positive and negative "banana plug" output ports on the front face of the power supply which are unacceptable for a high voltage power supply of this type. These ports were not in use and the power supply face had a small label stating that the high voltage connections were at the rear of the unit. It is not clear if the front panel output ports are still active in the power supply circuit. In addition, the "pig-tail" method of attaching the high voltage cable to the power supply is not a good practice and should be eliminated. An SHV output port should be provided.

V. Analysis

A review of the causal factors of this incident was conducted at the critique on 6/4/04 and at subsequent meetings. The following issues were evaluated:

1. The changes to the high voltage connections produced a dangerous configuration.

In seeking to reverse the polarity of the voltage applied to the sample, the students connected the center conductor of the high voltage cable to the grounded negative output of the power supply and connected the copper shield of the cable to the positive output. In this configuration, the outer shield of the cable and the shell of the SHV connector had a positive potential, and when the cable was connected to the vacuum tank feed-through, the power supply output was directly shorted to ground. If the connectors had been disconnected from the vacuum tank and held by someone (who was grounded) when the power supply was turned on, an electrical shock would have occurred.

The error occurred because the students did not understand the contacts at the rear of the power supply and the nature of the connections that they made. The polarity could have been successfully reversed if the center conductor had been connected to the negative output of the power supply and a connection was established to the positive output, chassis ground and the cable shielding. They apparently believed they were grounding the positive output when they connected the copper shield to the positive output. However, any changes to the configuration without the benefit of power supply documentation and guidance from personnel familiar with the power supply was a risky undertaking and contrary to the training received by the users and the responsibilities assigned to all users.

It should be noted that there were no electrical shocks to anyone produced by this unsafe configuration. Following the change of the high voltage connections by the students, the A.C. power was apparently not connected at the power supply. The students reported that there was no indication that the power supply was working, and the next user found the A.C. power cord was not properly seated. The next two user groups realized immediately that something was shorted in the system and handled the power supply and its cable and connectors with caution as they evaluated the set-up.

2. There was no review of the changes before they were made and there was no reporting of the change to the PRT after the fact.

There was an obvious and serious error in the re-configuration of the high voltage connection that review would have caught. The lead experimenter is responsible to ensure that any changes to beam line equipment are reviewed with the PRT personnel prior to implementation. In addition, the facility training that all users receive specifically states that electrical equipment maintained by others should not be worked on. It is unclear if these types of issues were covered in BLOSA training provided by the beam line PRT to these users in January 2004. The facility and beam line training should be re-examined to ensure that adequate emphasis is provided to configuration control. In addition, the process for conveying responsibilities to the principal investigator and lead experimenter should be re-examined to determine that roles and responsibilities are adequately conveyed.

The lack of reporting of the change to the PRT is also a significant concern. The lack of knowledge of the changes by subsequent PRT members created substantial operational and safety issues that could have been avoided by better communication.

3. There was little support for or oversight of the user group during the run.

Because of the limited staff support for this beam line, this user group had little on-going involvement with more knowledgeable staff. The NSLS co-local contact did stop by daily to see how things were going, and could have provided or made others available to provide guidance as to how the polarities could have been safely reversed. However, there was no discussion with him about the issue. There was no one else associated with the beam line physically present at the beam line to keep an eye on the status of the beam line and the actions of the users. The lack of PRT presence at the beam line is a serious obstacle to effective discharge of the responsibilities for safety that are assigned to PRT management and is a significant factor in this incident.

VI. Apparent Causes

1. Contrary to the training provided and to the responsibilities assigned to all users, unauthorized changes were made in the electrical configuration which resulted in an unsafe condition in the electrical circuit.

2. There was inadequate communication of the changes that were made to the electrical connections.

3. There was inadequate staffing to properly support the operation and oversight of the beam line.

VII. Corrective Actions

1. Meet with the Principal Investigator and the two students involved in this incident and review the error in judgment and deviation from procedures that resulted in this incident.

2. Meet with the Principal Spokesperson for the U4A beam line and review PRT capabilities to support operations and provide required oversight in an adequate manner.

3. Distribute summary information to NSLS PRT spokespersons and local contacts regarding this incident. Provide particular emphasis on the need for PRTs to provide comprehensive BLOSA training and to maintain configuration control of hazardous equipment.

4. Examine the current NSLS facility specific training for users and provide additional instructions as warranted regarding configuration control for potentially hazardous equipment.

5. Examine beam line BLOSA training and ensure appropriate emphasis on configuration control of potentially hazardous equipment.

6. Examine and reinforce as needed the communication of ESH responsibilities by the PRT and the NSLS to the Principal Investigator and the Lead Experimenter.

7. Conduct a review of high voltage power supplies used with experimental equipment to ensure proper labeling and configuration.

Attachment 2

I. Note from Students Describing Event

"In order to reproduce a previous study performed at the Stanford Synchrotron Light Source, we wanted to bias the sample with 100V while performing photoelectron spectroscopy. We talked to Dr. Steve Hulbert about the procedure for biasing the sample, and ultimately biased the sample using the high voltage power supply at the beam line with proper connectors as advised. However, the biasing happened to be of the wrong polarity than we required and therefore we turned off the power supply and switched the non-earth power output wires with one another. We did properly secure the earth connection with one of the wires as we put them back. The power supply was not seem to output any voltage in this configuration, and we decided to try it again the next day before we reversed the changes we made. Unfortunately, we got preoccupied with other experimental details in the course of our short run period and overlooked making this change back to the original configuration. We apologize for not setting the equipment to its original settings."

II. Note from a Boston University post-doc who ran at U4A from May 29 – June 1

"I had beamline at U4A starting Saturday (May 29, 2004) morning. The group before was from University of Delaware. They actually gave me a favor and inserted my sample into the main chamber and started annealing it for me already Friday night.

I was attempting to use high voltage power supply on Saturday to test e-beam heating which is important for my experiments. My first attempt was probably sometime in the afternoon. I tried to switch the power supply on but it behaved like unplugged. I noticed that the black 120 VAC cable was unplugged at the back of the power supply (inside the cage). I plugged it back in without opening the cage - I used screwdriver to pull the cable into the plug.

After that I could switch the power supply on. However, at any attempt to get high voltage the power supply was immediately going to the current mode and there was impossible to get any high voltage. I suspected the short inside the vacuum chamber and basically gave up. I contacted Ally Chan (left her voice mail on the cell-phone) and told her that e-beam heating does not work. At this point I decided to make experiment wihout e-beam heating. I left the beamline around 2 am on Saturday/Sunday night.

On Sunday I did several attempts to use high voltage power supply. The attempts were just switching the power supply on. There has been always the same problem - it was immediately going to current mode. These attempts were motivated by the fact that I thought the problem was inside vacuum chamber (short-circuit on the manipulator) -

frequent annealing of the sample could change this situation. I left the beamline around 4 am on Sunday/Monday night.

On Tuesday (June 1st) I continued measurements at U4A. I called Ally Chan again and we talked a little bit about the e-beam heating problem. She suggested to check short high-voltage cable which is typically plugged in to the chamber. I did that but the cable was fine and there was still the same problem with the high voltage power supply. I didn't spend more than 20 minutes investigating this since I thought the problem is inside the vacuum chamber (which is not possible to solve without venting). I left the beamline around 4 am on Tuesday/Wednesday night.

I actually realized what has happened only on Thursday. I think that the problem is serious and I could have been seriously injured during my last weekend beamtime."

III. Note from Rutgers Group who returned to U4A on June 2nd

"My colleague and I arrived at BNL on Wed, June 2, and tested the HV supply in order to perform electron beam heating of our sample. A part of this heating procedure involves applying 1.2 to 1.4 kV to our sample, which is inside the vacuum chamber.

The HV supply output is via a red SHV cable, connected to a shorter SHV cable that is connected directly to the chamber. With all connections in place, we turned on the HV supply and observed that it went into current mode, instead of the expected voltage mode if the unit was operating normally. We then disconnected the HV supply from the chamber to check that there is no short inside the vacuum chamber. Our standard practice is to always turn off the HV supply when we connect/disconnect it from the chamber, so that we never handle the SHV cable when it is electrically 'hot'.

Having determined that there is no short inside the chamber, we concluded that the problem must lie with either (a) the HV supply, and/or (b) the cables leading from the HV supply to the chamber. We removed the shorter SHV cable from both the HV supply and the chamber, and checked that its shielding was properly grounded from its center pin. Finally, we checked the SHV cable coming from the HV supply, and observed sparks when the shield of that SHV connector is contacted with ground, for e.g. the chamber. Note that these diagnostics were performed using a lower voltage (~200 V), and not the 1.2 to 1.4 kV used during standard operation. At this point, we reported the problem to Gary Nintzel, and demonstrated to him that the SHV connector shield is electrically 'hot'. After that, we turned off the HV supply, and did not use it further."